Dealing with 3D issues in cloud-vegetation interactions

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Clouds with Low Optical (Water) Depth ("CLOWD")

– Over 50% of the warm liquid water clouds at the SGP site have LWP < 100 g m^{-2}

– MWR's uncertainty is 20-30 g m^{-2} (i.e., errors of 20% to over 100%)

– Aerosol indirect effect research needs accurate measurements of LWP and effective radius

courtesy of Dave Turner, PNNL
Presentation at the ARM STM 2004

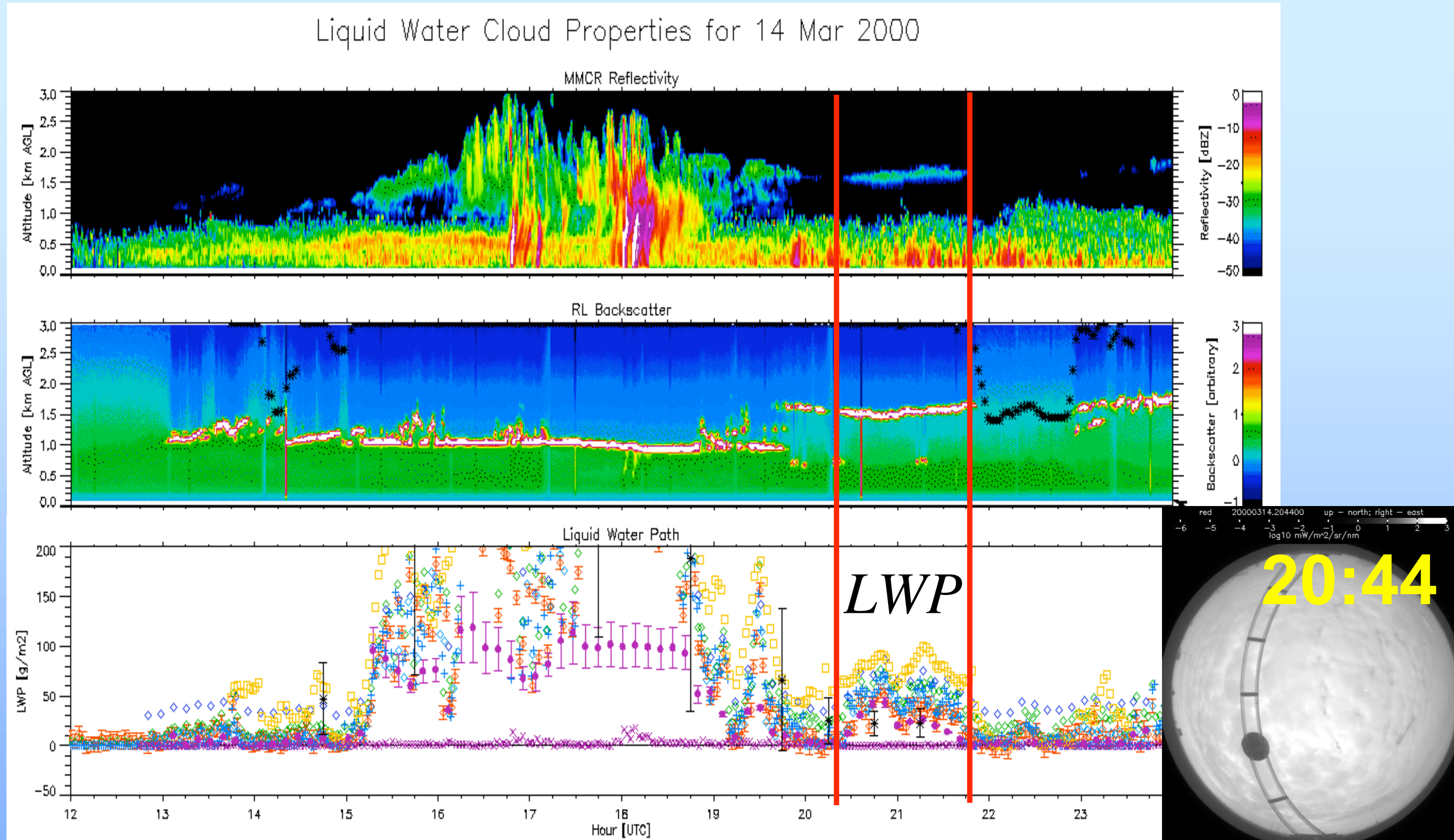
Intercomparison between different retrievals of cloud LWP

(easy case: Variable Thickness Stratus Case)

Radar reflectivity

Raman lidar backscatter

Comparisons among many volunteered methods for retrieving the low LWP



Results from 14 Mar in the ARM 2000 Cloud IOP at the ARM SGP site, a day (esp. around 21 UT) when the cloud was particularly stratiform and uniform

courtesy of Dave Turner, PNNL
Presentation at the ARM STM

Retrieval of cloud optical depth

Common approach is to use downward fluxes:

- broadband pyranometers

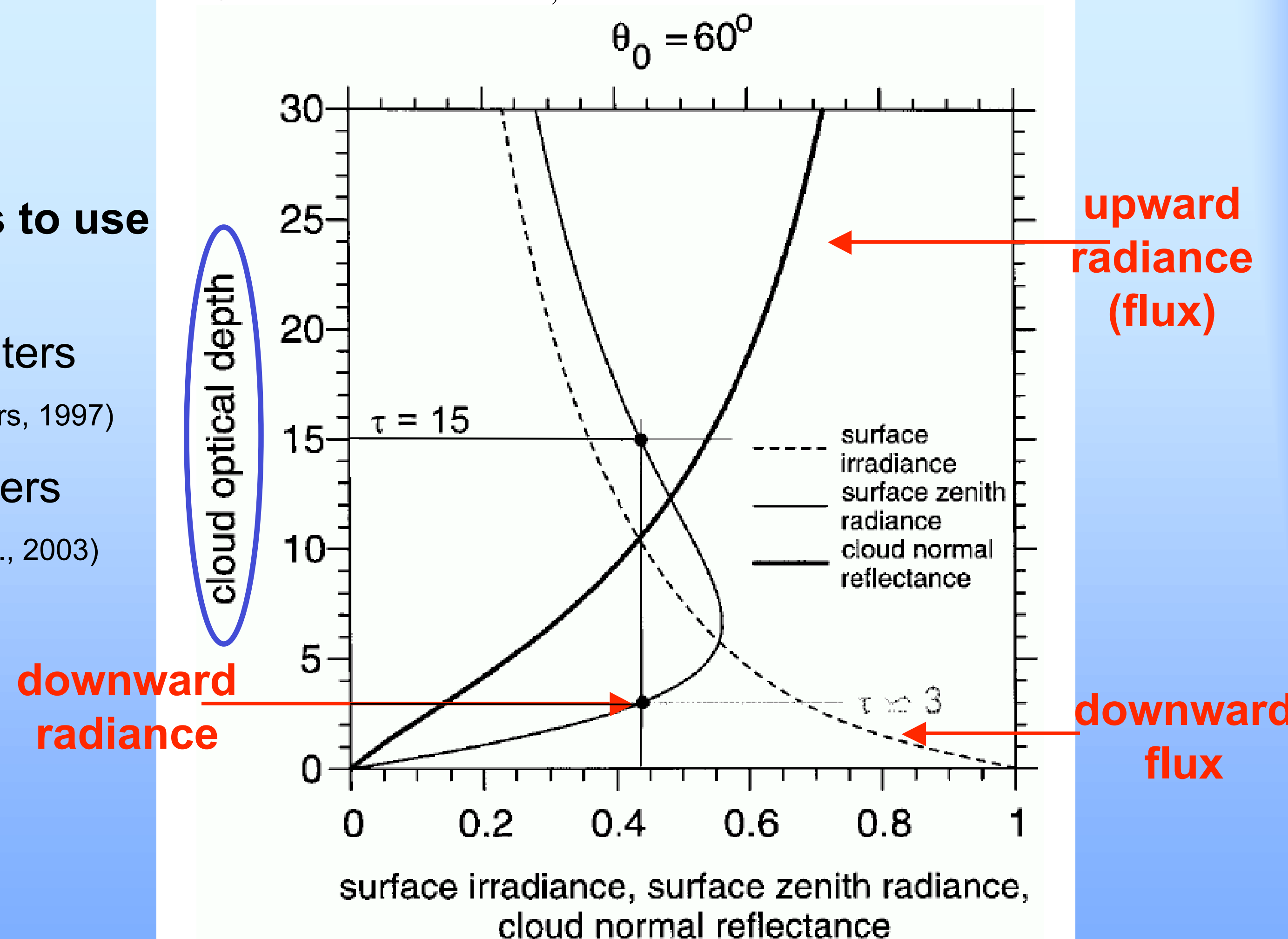
(Leontieva & Stamnes, 1994; Boers, 1997)

- narrowband radiometers

(Min and Harrison, 1996, Min et al., 2003)

2990 JOURNAL OF THE ATM

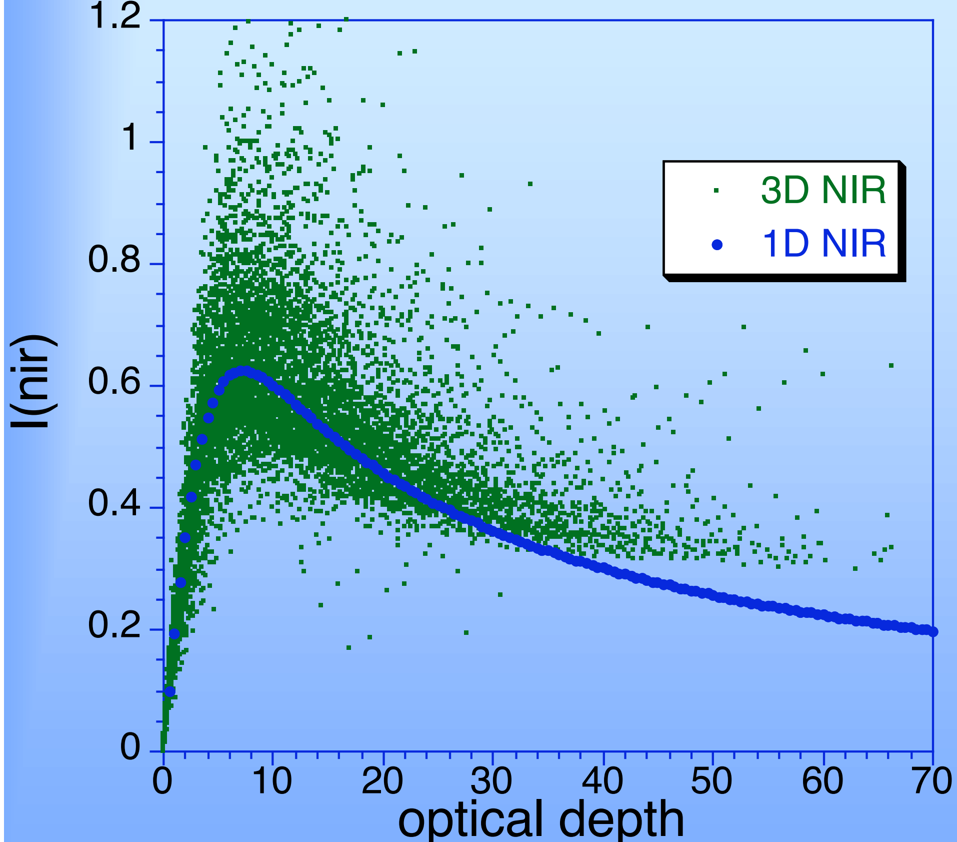
from Barker and Marshak, JAS 2001



computed by DISORT: g=0.85, ϖ_0=1, ρ_{surf}=0.2

Ground-based retrieval from measurements of zenith radiance

zenith radiance in NIR from *simulated* 3D clouds



Three major problems with inferring cloud optical depth:

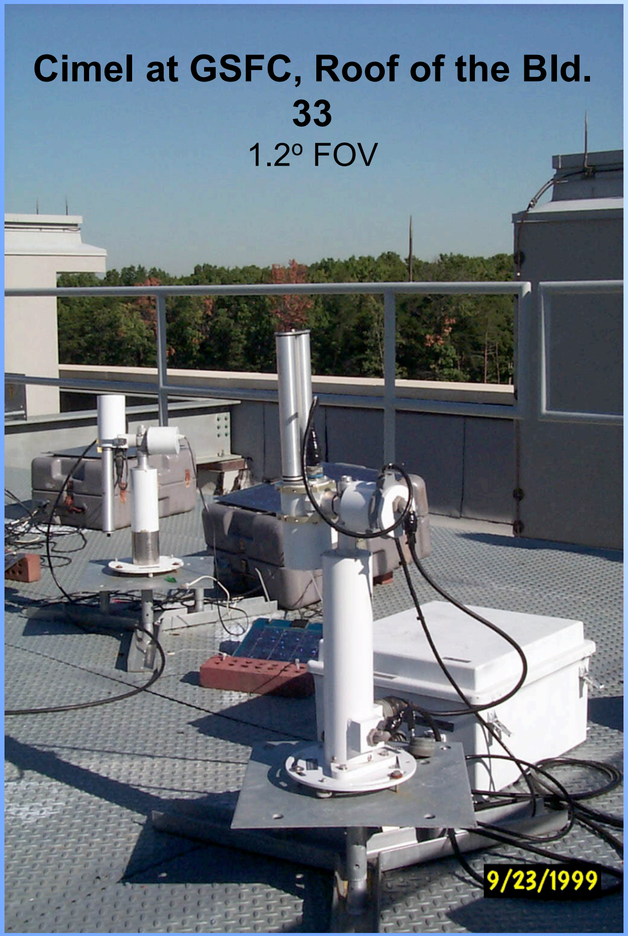
(i) lack of one-to-one relationship even for "plane-parallel" 1D clouds;

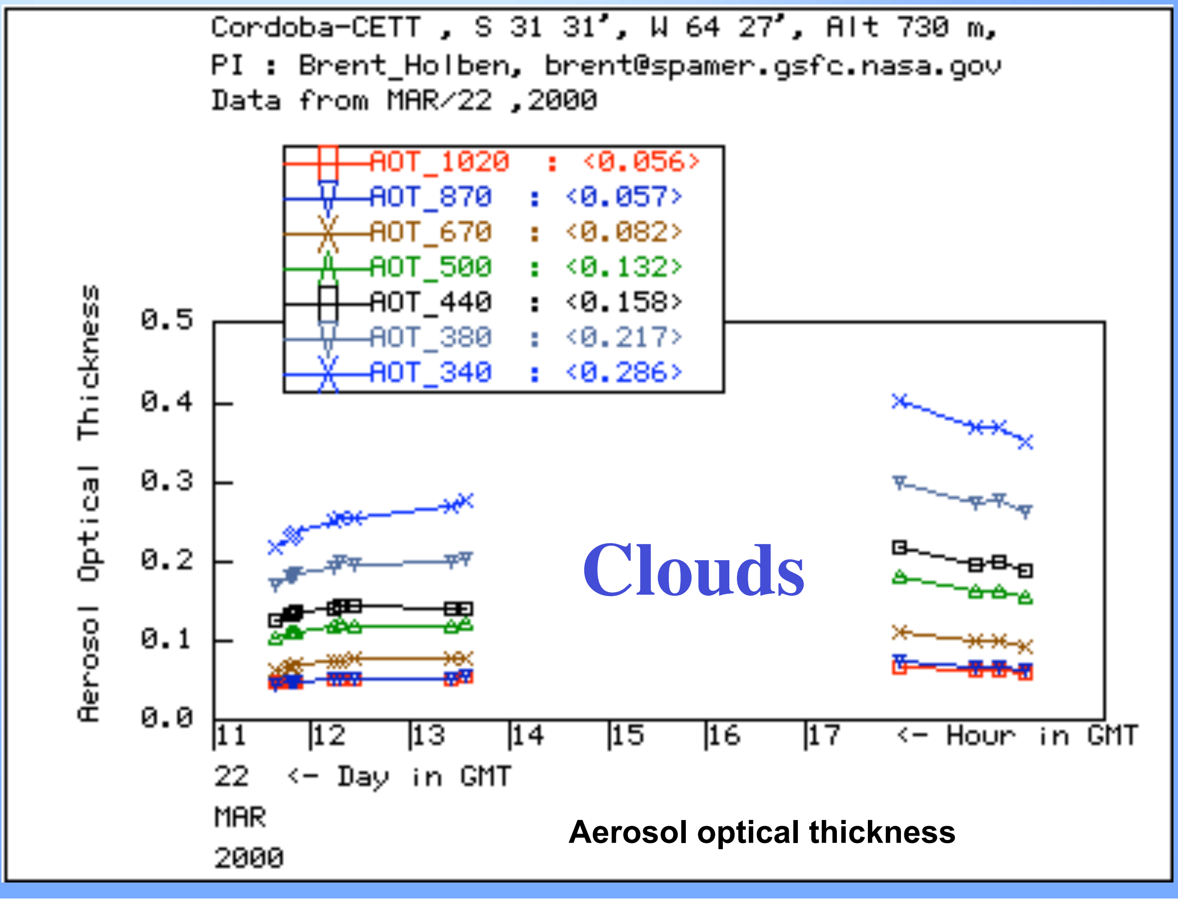
(ii) a strong influence of 3D cloud structure on measured radiance;

(iii) no retrieval for 3D values larger than max of 1D.

AERONET

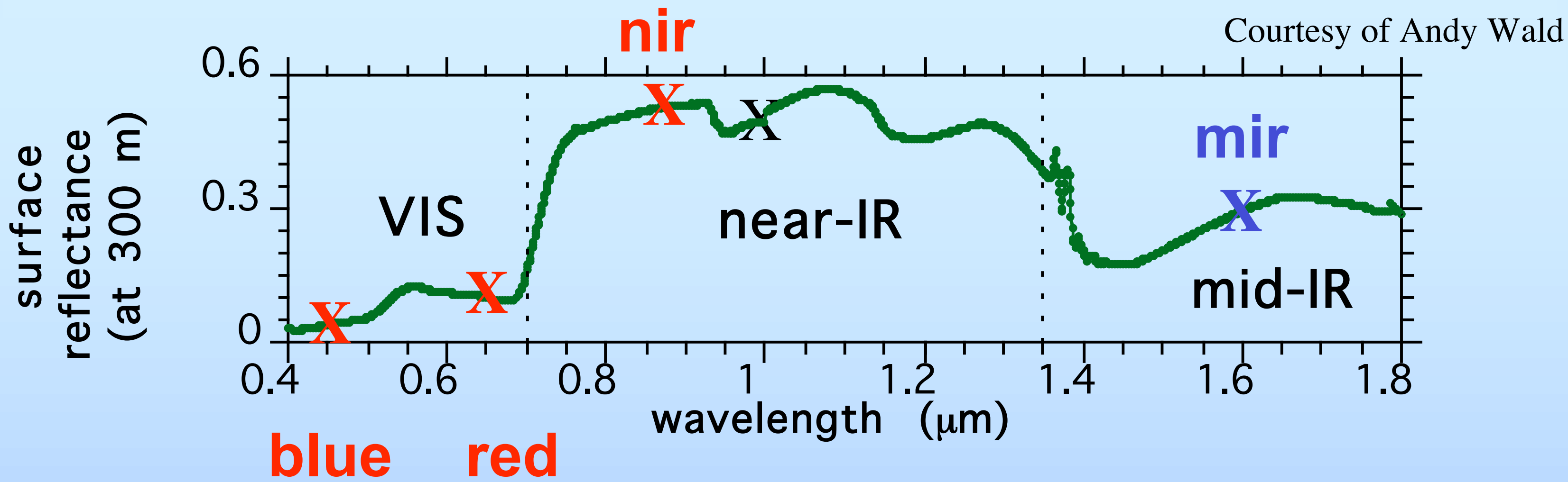
AERONET is a ground based monitoring network that consists of identical multi-channel **Cimel** radiometers for assessing *aerosol* optical properties





Aerosol optical thickness

Cimel channels and surface reflectance

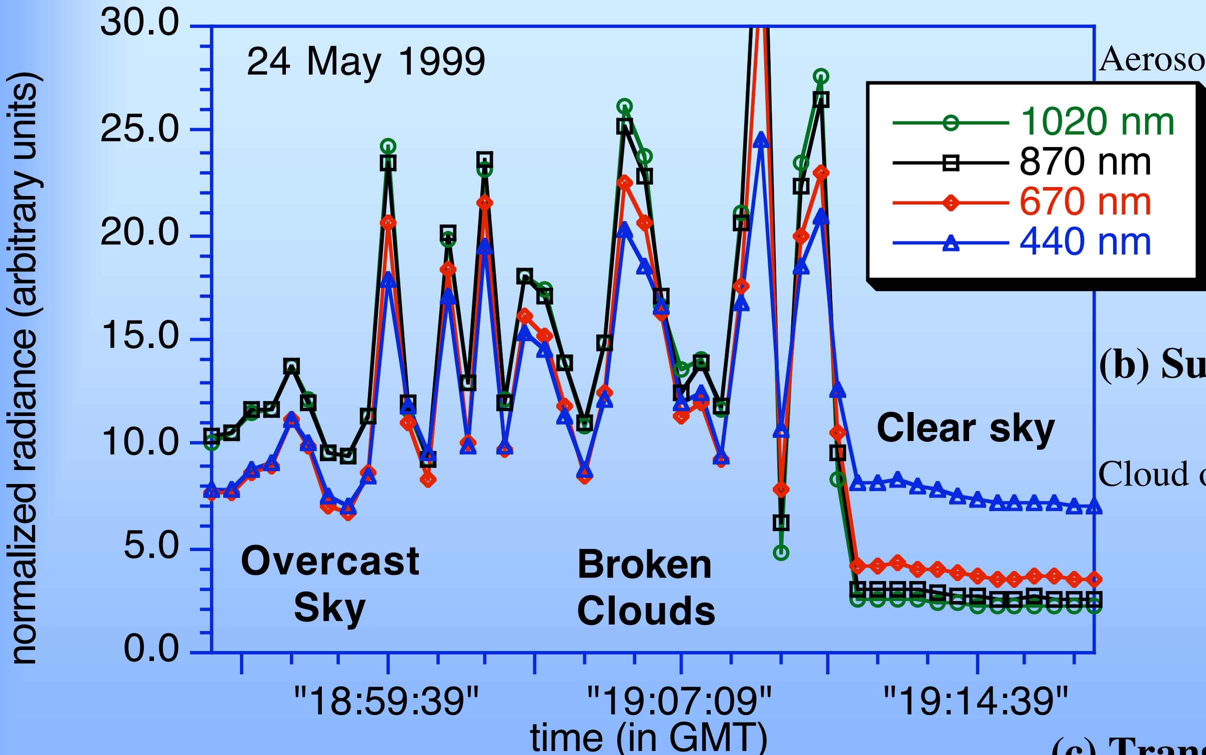


Objectives

• to exploit the sharp spectral contrast in vegetated surface reflectance between **0.67** and **0.87 μm** to retrieve cloud properties from measurements of zenith radiance;

• to study possibility of simultaneous retrieval of droplet effective radius from measurements of zenith radiance at **0.87** and **1.64 μm** spectral regions

Cimel radiance measurements (GSFC, Bld. 33): four channels (440, 670, 870, and 1020 nm)



(a) Atmosphere dominates:

$$I_{440} > I_{670} > I_{870} > I_{1020}$$

Aerosol optical properties can be retrieved

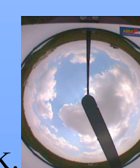
(b) Surface and Clouds dominate:

$$I_{440} \approx I_{670} < I_{870} \approx I_{1020}$$

Cloud optical properties can be retrieved

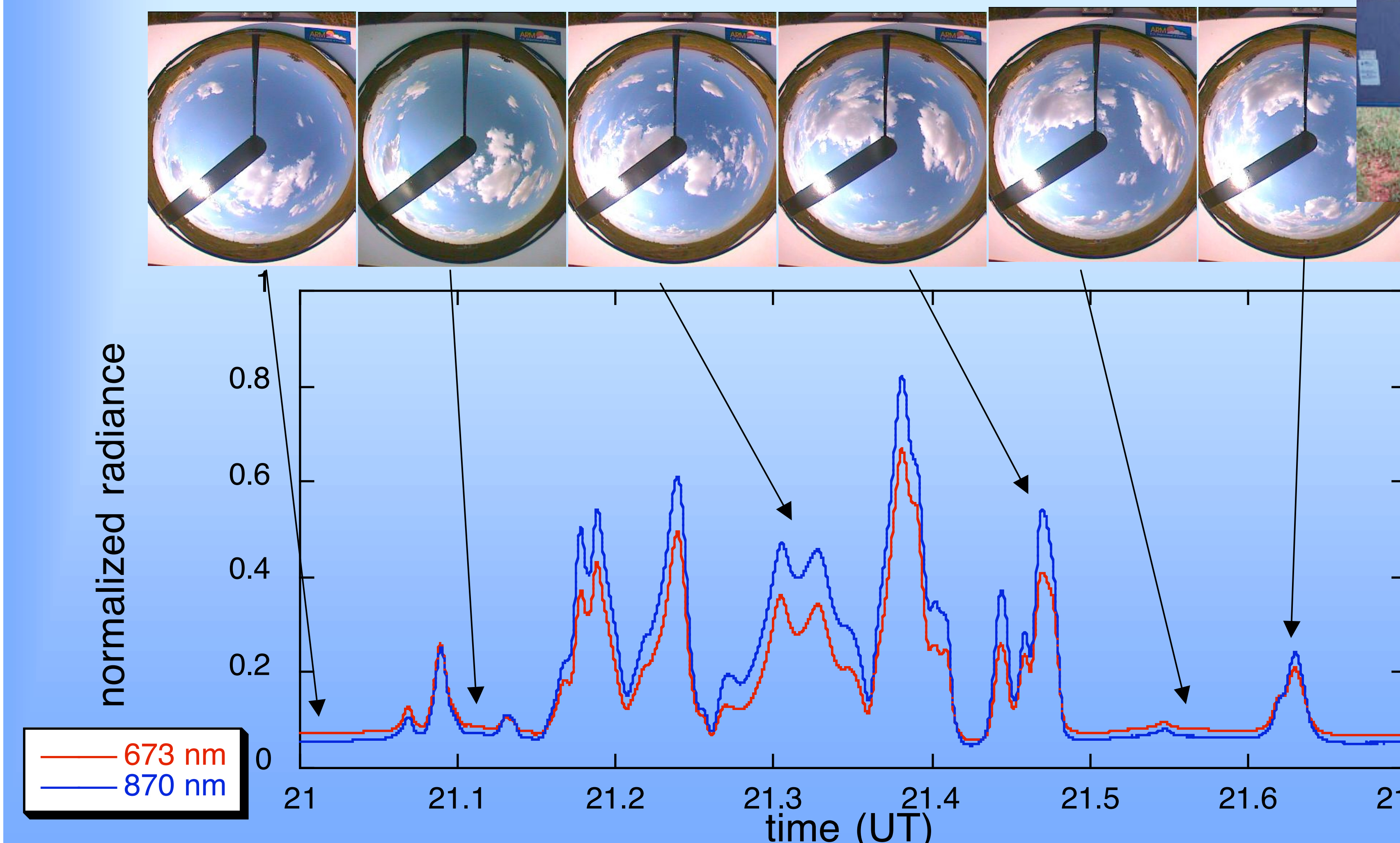
(c) Transition between (a) and (b):

- sharp changes in I_λ around cloud edges;
- the "order" of I_λ between all four channels rapidly changes from cloudy to clear and back.



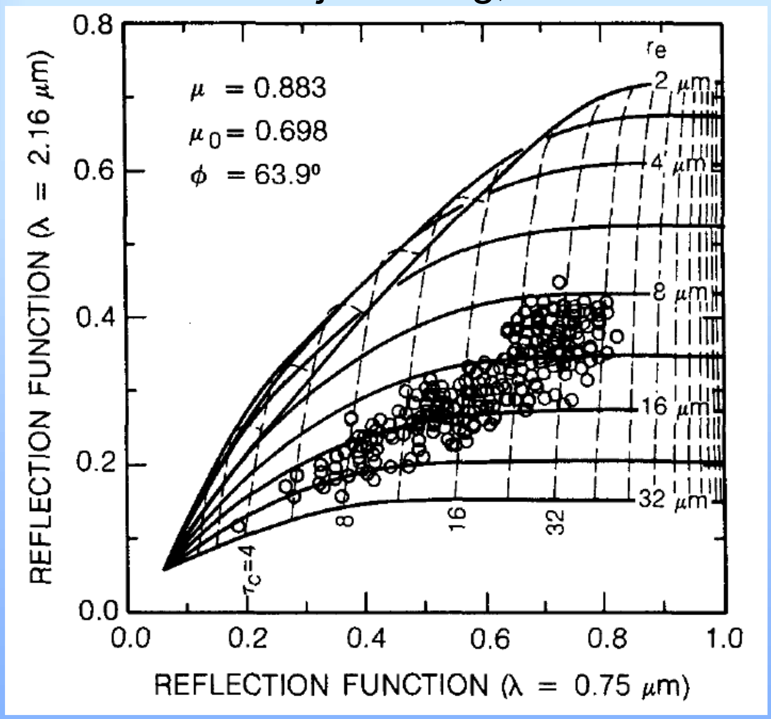
Two-Channel Narrow Field of View (NFOV)

September 29, 2004; ARM SGP

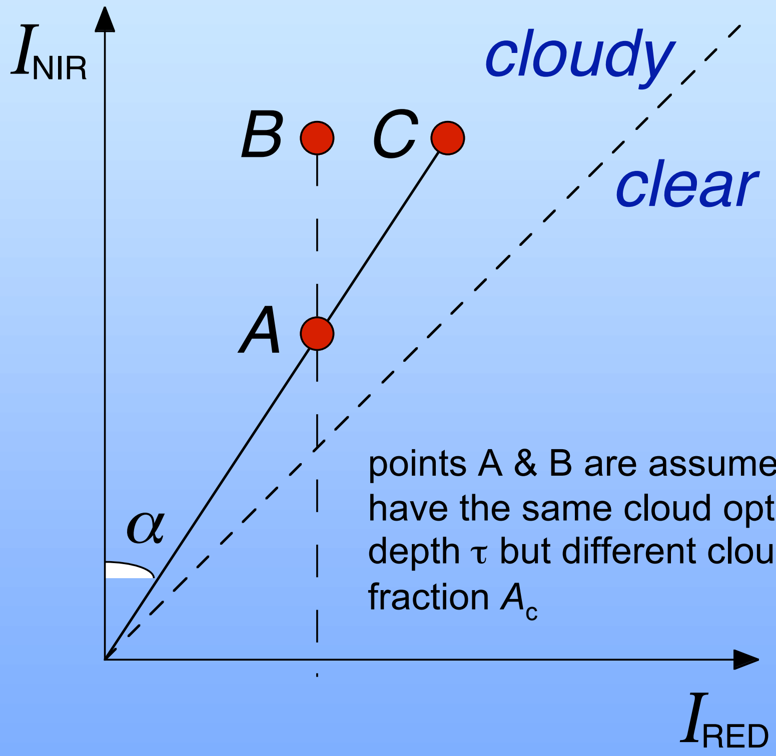


Two-channel cloud retrievals

Satellite retrieval of τ and r_e
from Nakajima-King, JAS 1990

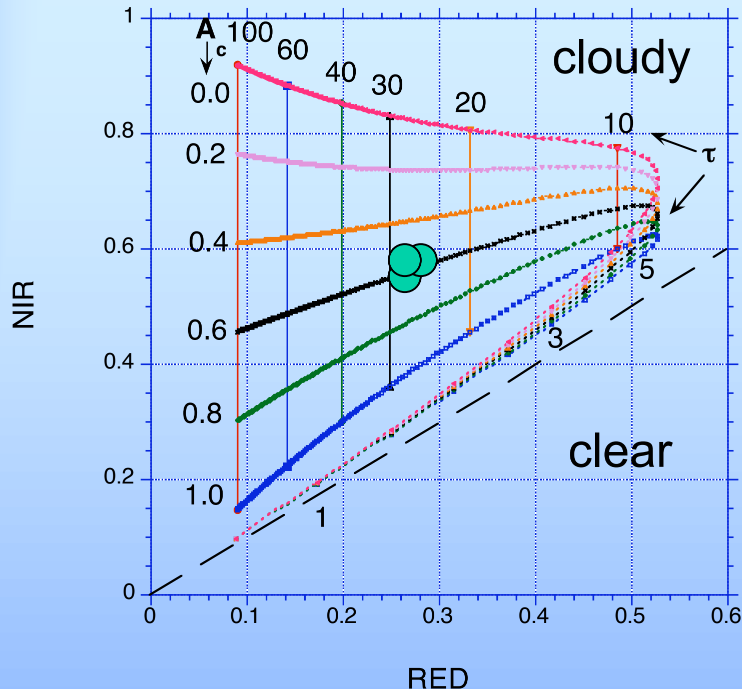


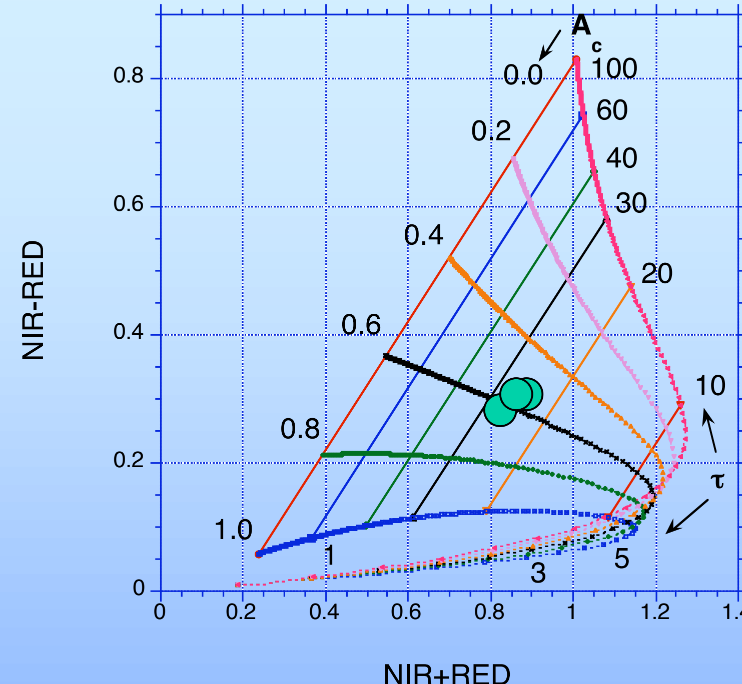
Surface retrieval of τ and A_c
from Marshak et al., JAS 2004



points A & B are assumed to have the same cloud optical depth τ but different cloud fraction A_c

2D Look-Up Tables
"NIR vs. RED" plane





$I_{RED} = I_{RED}(\tau, A_c)$

$I_{NIR} = I_{NIR}(\tau, A_c)$

τ is cloud optical depth

A_c is "effective" cloud fraction

Where are Cimel data-points?

July 28, 2002 ARM CART site in OK

Cimel measurements taken around 13:45, 13:58 and 14:11 UT

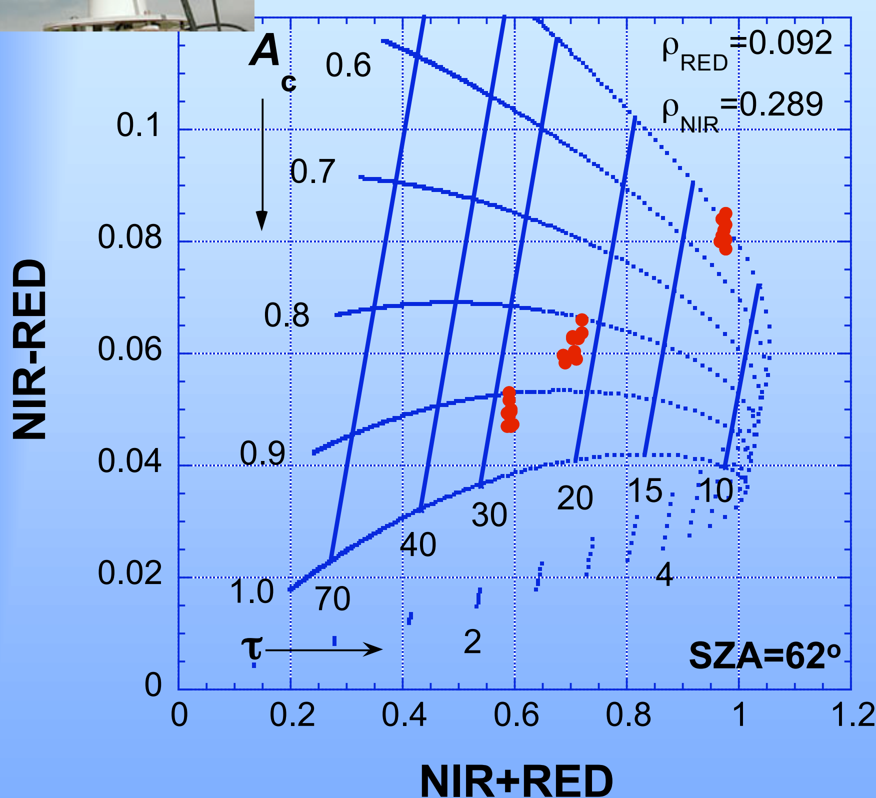


Image from Total Sky Imager

14:00 UT

A_c = 0.85 is not a visual cloud fraction but a “radiatively effective” one that also compensates for cloud horizontal inhomogeneity not accounted for by 1D RT.

Retrieval examples

August 8, 2002;18:00 UT CART site

Cloud optical depth retrieved from:

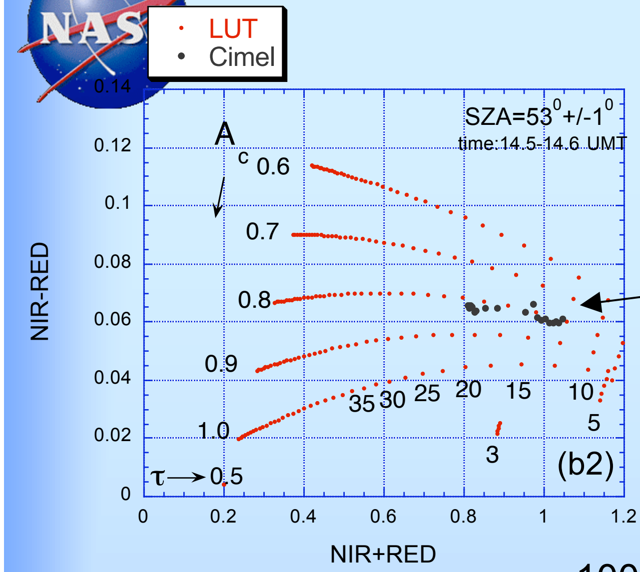
• **Cimel** (spectral zenith radiance)

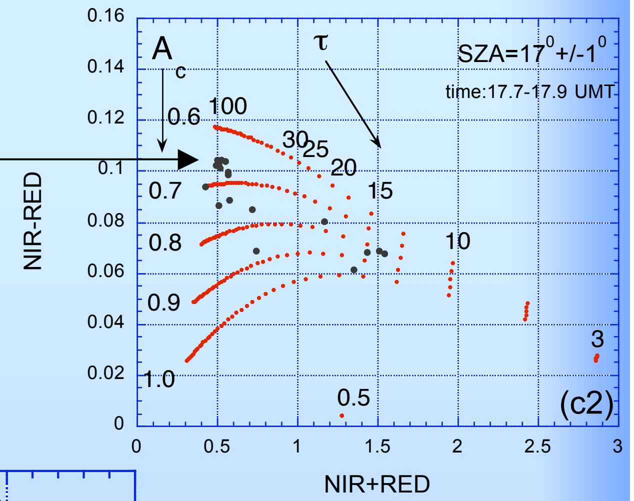
• **MWR** (Microwave Radiometer) assuming $r_e = 7\ \mu m$

• **MFRSR** (Multi-Filter Rotating Shadowband Radiometer)

Retrievals

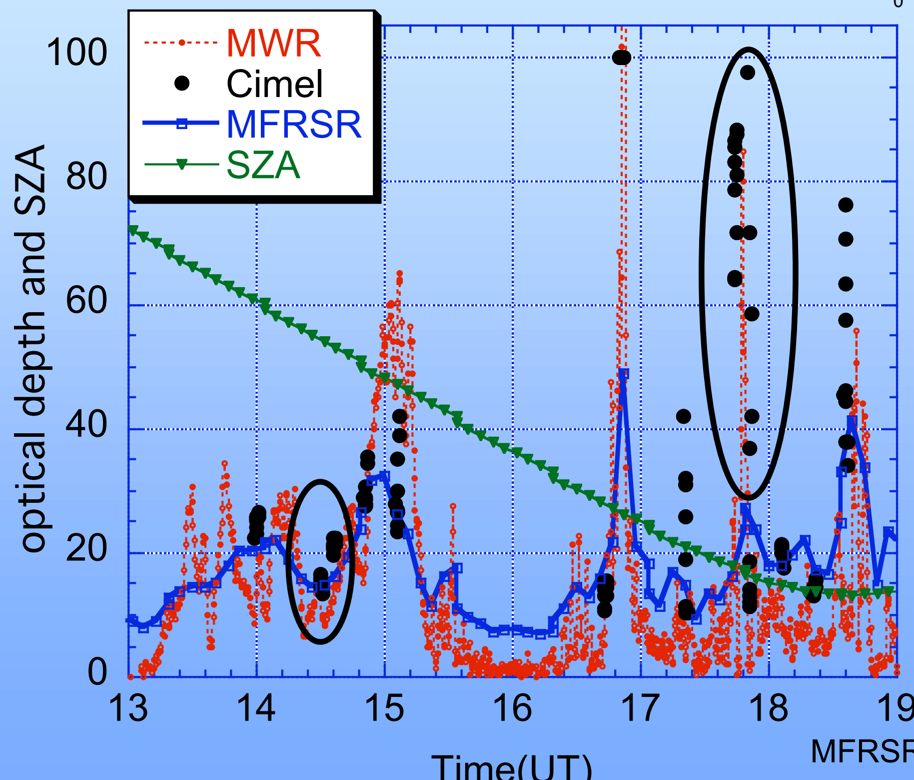
LUT
with Cimel data-points





July 3, 2002

SZA=52.3
Time: 14:36



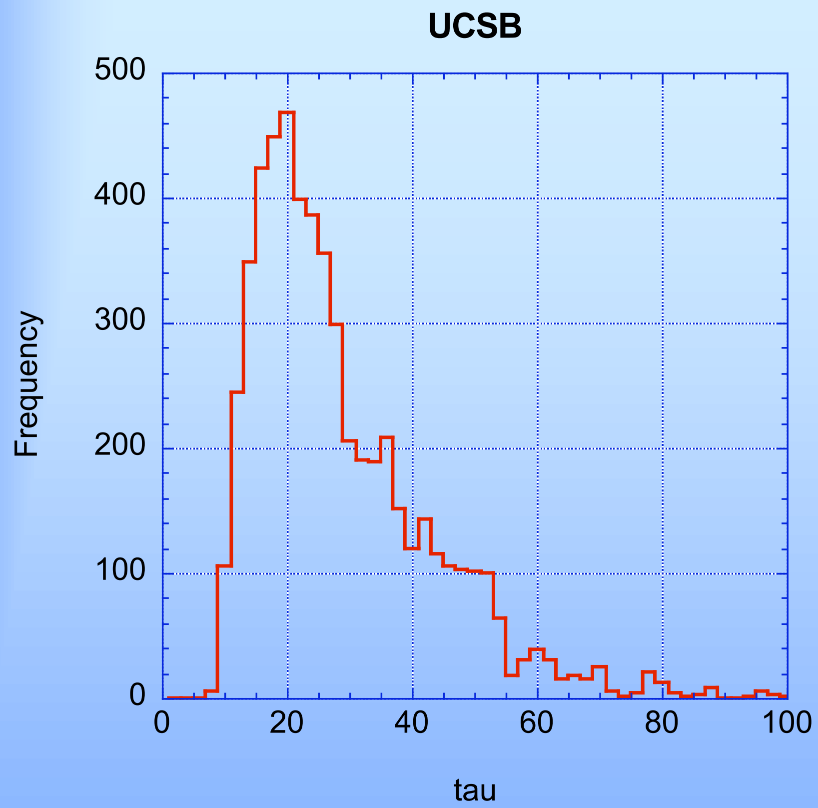
SZA=16.3
Time: 17:50

MFRSR data is courtesy of Q. Min

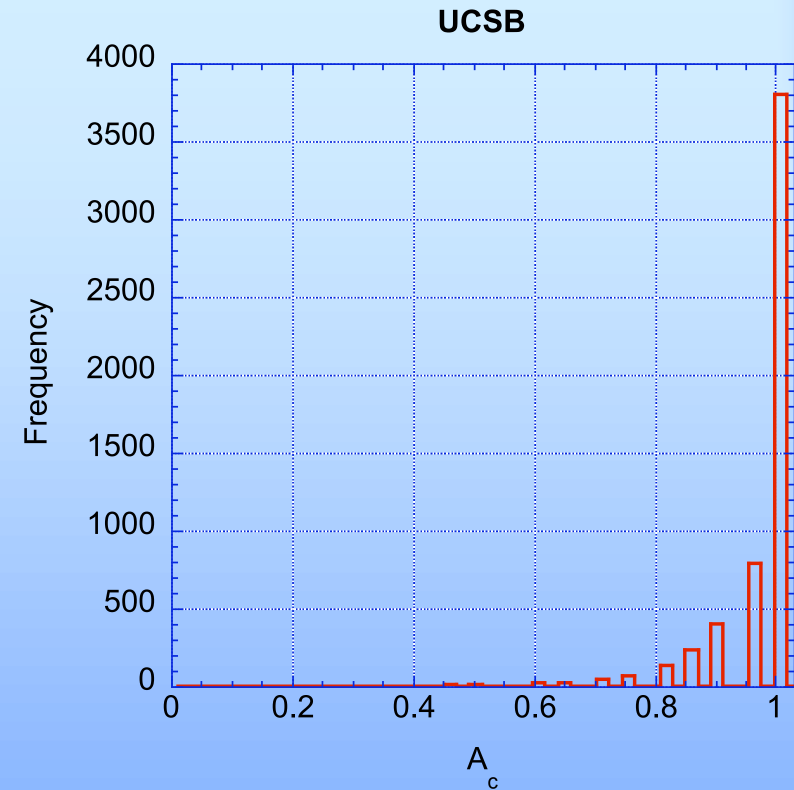
Retrievals from broken Cu clouds

Show MOVIES

Local climatology
(Santa Barbara, CA: 2003)



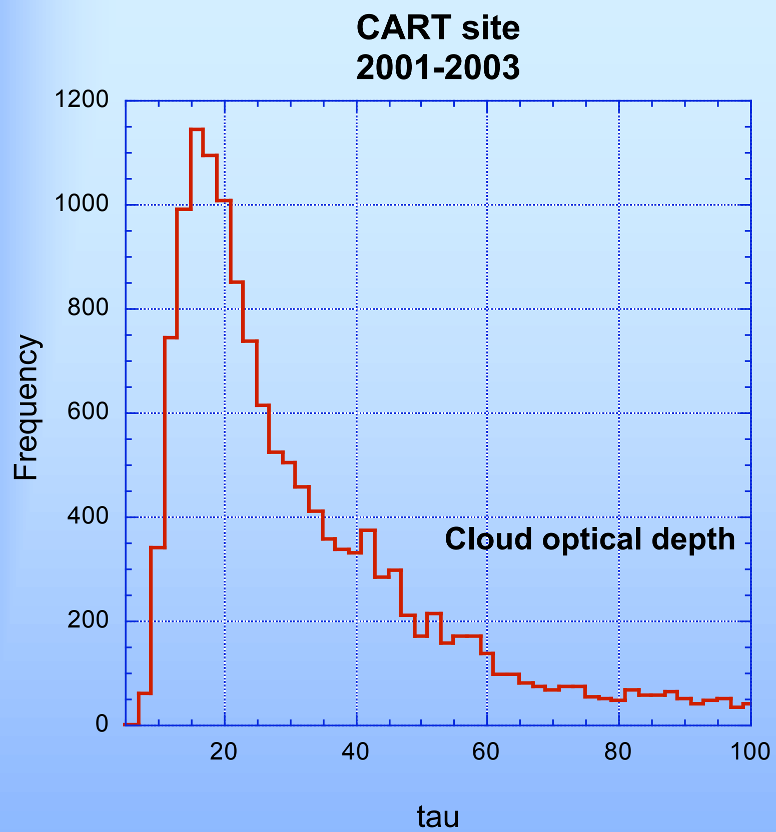
Cloud optical depth



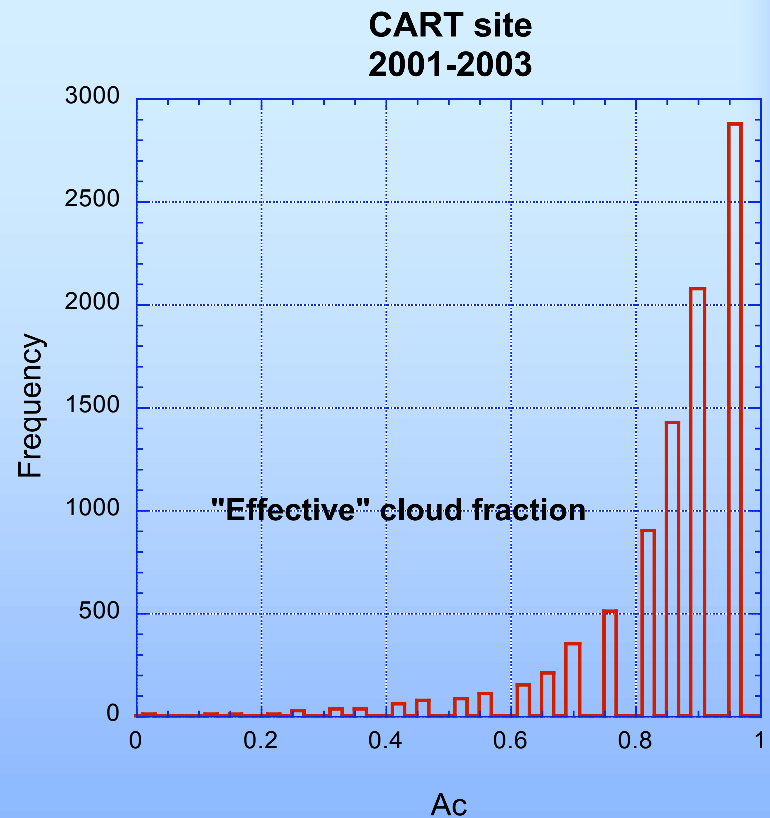
"Effective" cloud fraction

Local climatology

(ARM CART cite, OK: 2001-2003)

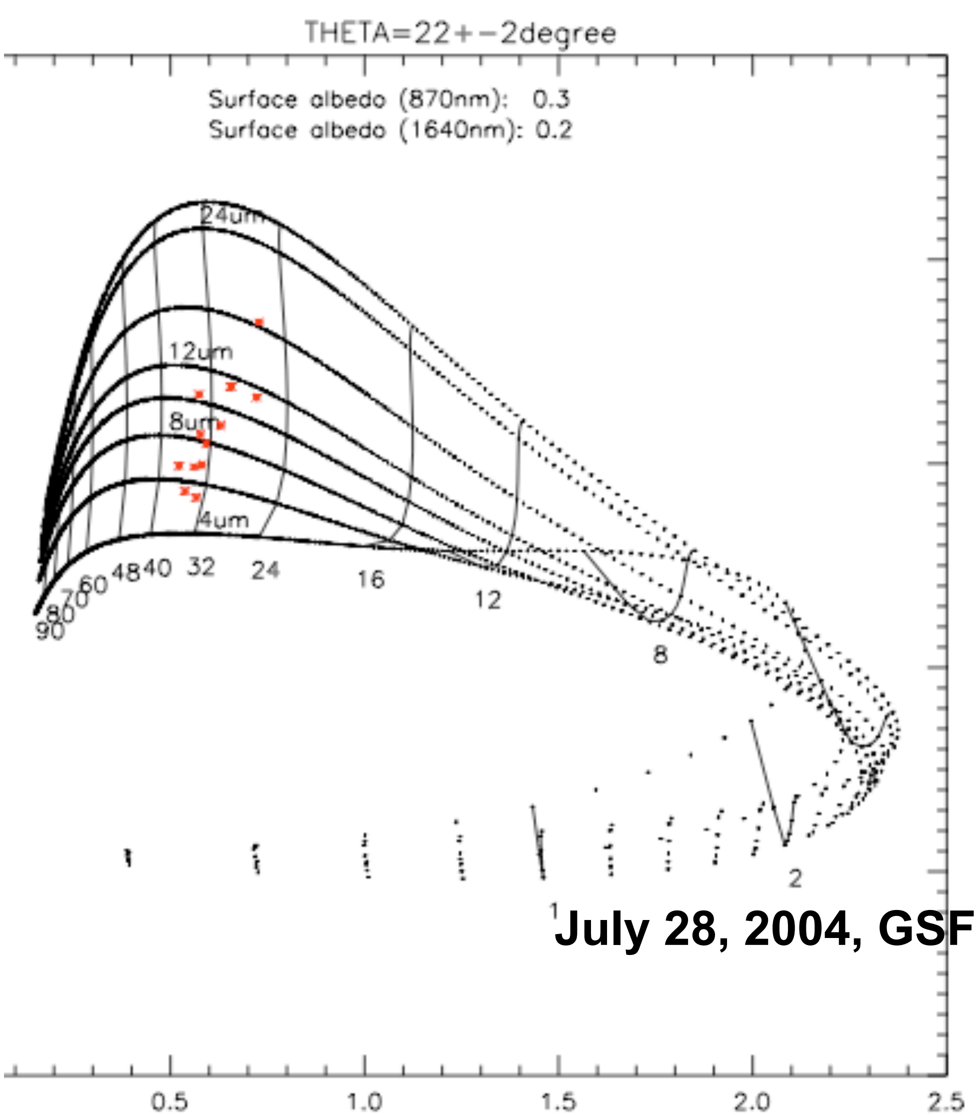


Cloud optical depth



“Effective”cloud fraction

Cloud droplet effective radius from Cimel

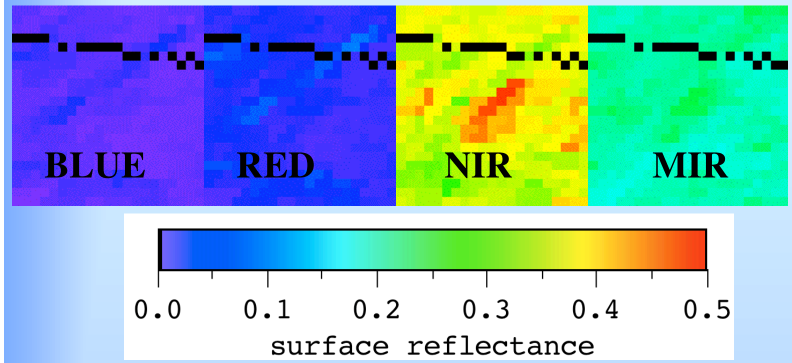


LUT

- LUT for two wavelengths: **870** and **1640** nm;
- Cimel measurements *I*(870) and *I*(1640);
- Surface albedo from MODIS/MISR

Difficulties (Platnick, 2000):
- less sensitive to droplet size;
- canceling effect of ω_0 and g.

Combined retrieval of
optical depth τ, (effective) cloud fraction A_c, and droplet effective radius r_e



MODIS surface refl. around Bld. 33 at GSFC averaged over 8 days starting from July 27, 2004. Data are 11 by 11 km with 500 m resolution (22 by 22 pixels).

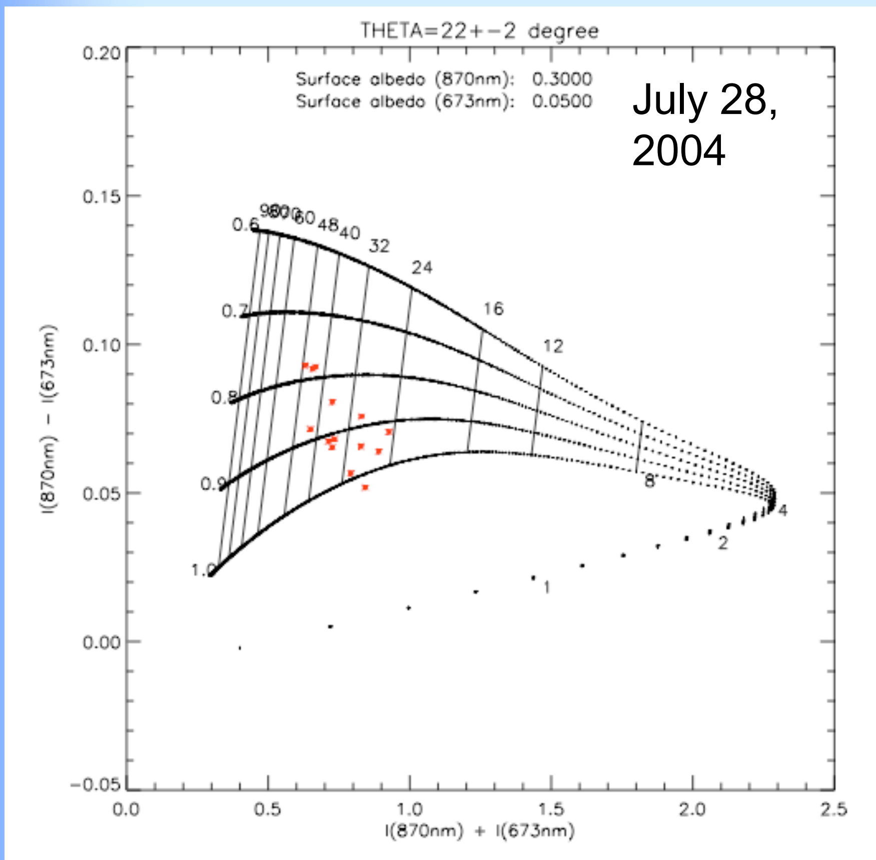
Assuming that surface albedos: α_{670}, α_{870}, α_{1640} are known,

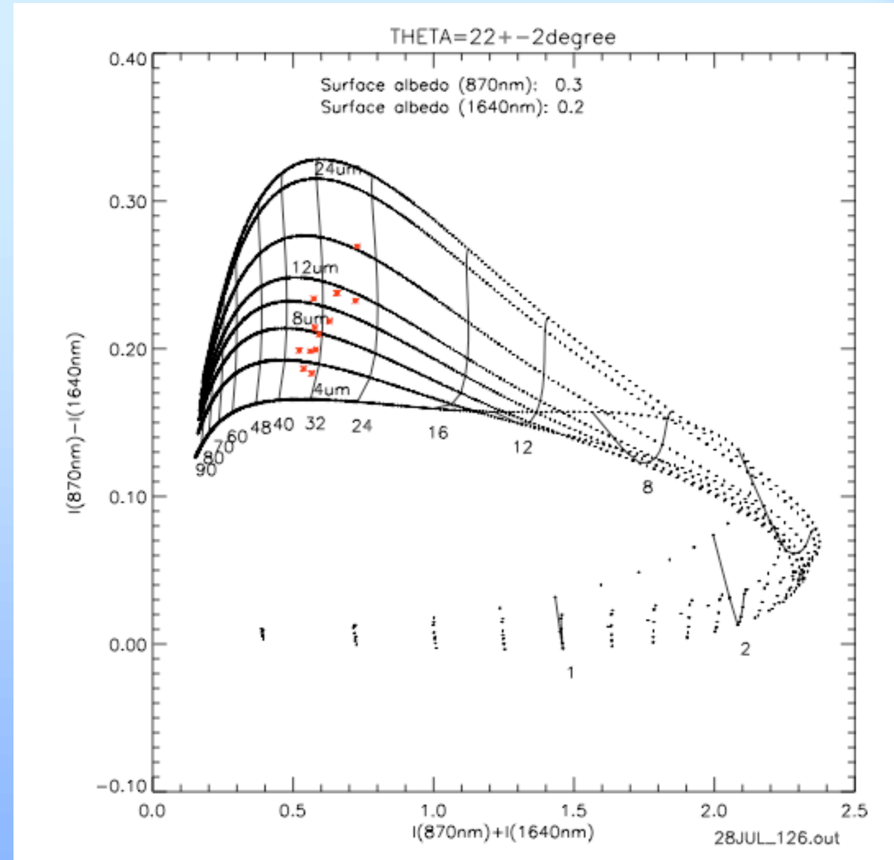
we have

$$I_{670} = I_{670}(\tau, A_c, r_e)$$
$$I_{870} = I_{870}(\tau, A_c, r_e)$$
$$I_{1640} = I_{1640}(\tau, A_c, r_e)$$

Two-step retrieval of

optical depth τ, (effective) cloud fraction A_c, and droplet effective radius r_e





1st step:

$I_{670} = I_{670}(\tau, A_c, r_e)$

$I_{870} = I_{870}(\tau, A_c, r_e)$

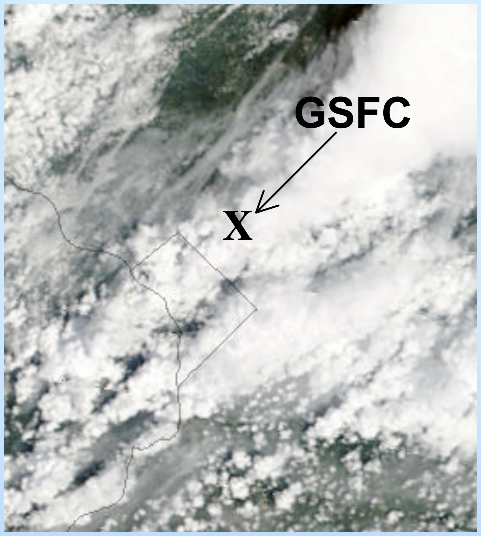
2nd step:

$I_{870} = I_{870}(\tau, A_c, r_e)$

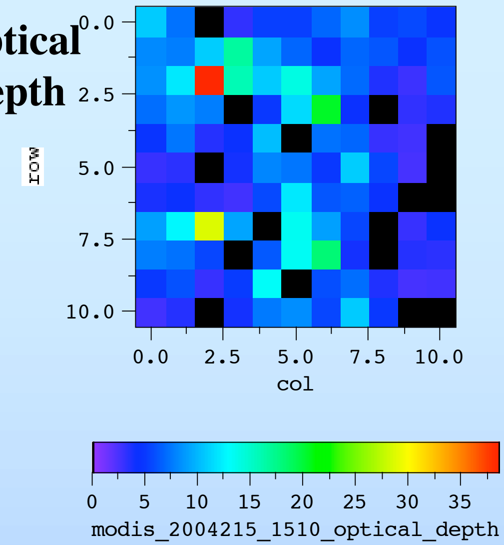
$I_{1640} = I_{1640}(\tau, A_c, r_e)$

August 2, 2004; GSFC

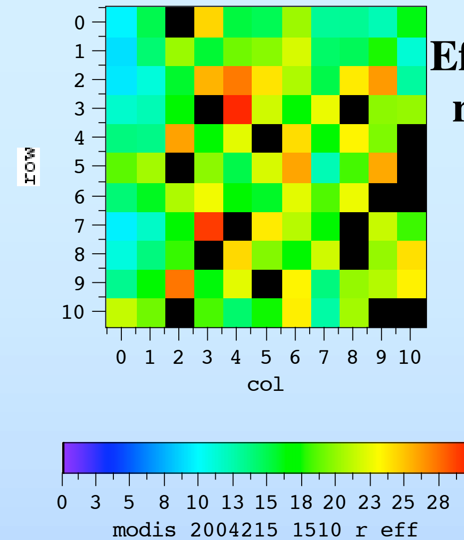
MODIS



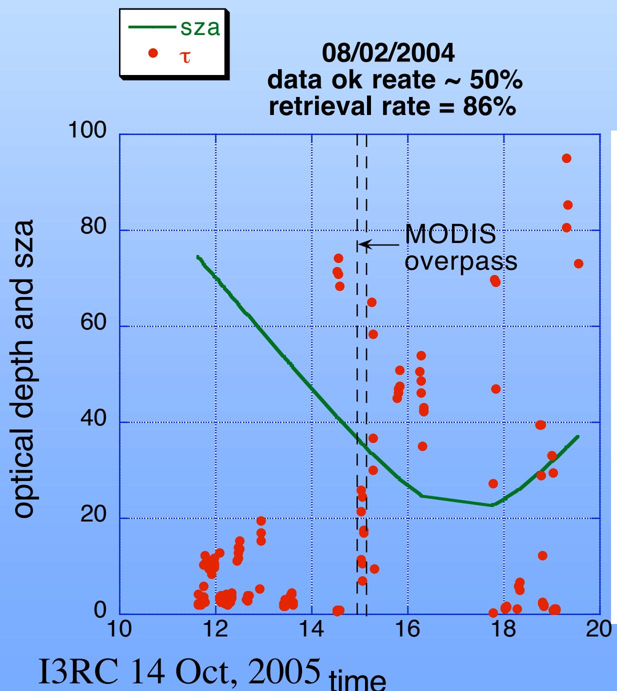
Optical depth

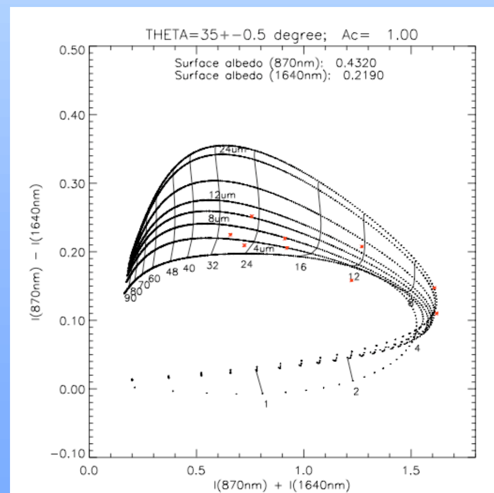


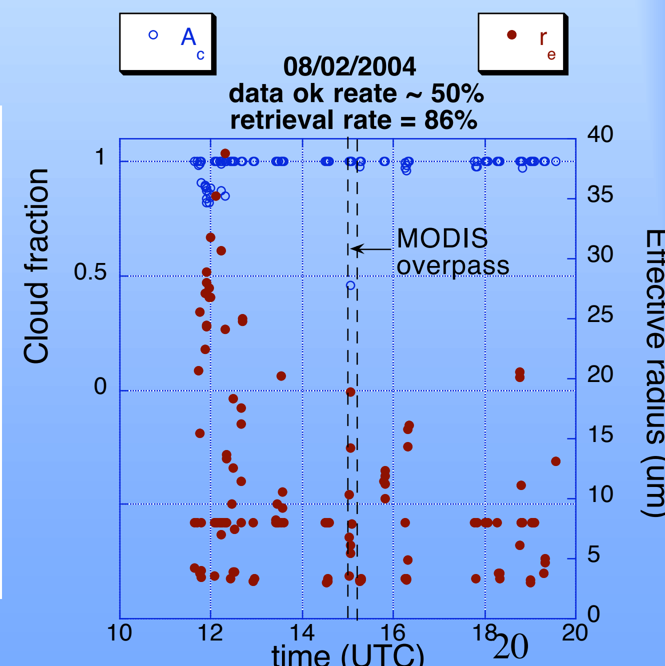
Effective radius



CIMEL







Alexander Marshak

Some theory behind the RED vs. NIR method

(Marshak et al., 2004)

$$I = I_o + \frac{\rho I_s T_o}{1 - \rho R}$$

$$T_o = 1 - A_c + A_c \cdot T_{o,pp}$$

$$I_{RED}\left(\tau, A_c\right) = I_{o,RED}\left(\tau\right) + \frac{\rho_{RED} I_{s,RED}\left(\tau\right) \cdot \left[1 - A_c + A_c T_{o,pp,RED}\left(\tau\right)\right]}{1 - \rho_{RED} R_{RED}\left(\tau\right)}$$

$$I_{NIR}\left(\tau, A_c\right) = I_{o,NIR}\left(\tau\right) + \frac{\rho_{NIR} I_{s,NIR}\left(\tau\right) \cdot \left[1 - A_c + A_c T_{o,pp,NIR}\left(\tau\right)\right]}{1 - \rho_{NIR} R_{NIR}\left(\tau\right)}$$

Some theory behind the COUPLED method

(Barker and Marshak, 2001, Knyazikhin and Marshak, 2005)

$$I = I_o + \rho I_s \underbrace{\frac{T_o}{1-\rho R}}_{=T}$$

$$I_{RED} = I_{o,RED} + \rho_{RED} T_{RED} I_{s,RED}$$

$$I_{NIR} = I_{o,NIR} + \rho_{NIR} T_{NIR} I_{s,NIR}$$

Assumptions:

$$I_{o,NIR} = I_{o,RED}$$

$$I_{s,NIR} = I_{s,RED} = I_s$$

$$I_{NIR} - I_{RED} = \left(\rho_{NIR} T_{NIR} - \rho_{RED} T_{RED}\right) I_s(\tau)$$

$$I_s(\tau) = \frac{I_{NIR} - I_{RED}}{F_{NIR}^{\uparrow} - F_{RED}^{\uparrow}}$$

$$I_{NIR}(x) - I_{RED}(x) = \int_{x' \in S} \left[F_{NIR}^{\uparrow}(x') - F_{RED}^{\uparrow}(x')\right] \cdot J(x,x')\,dx',$$

$$r_\lambda(x) = \frac{\int_{x' \in S} F_\lambda^{\uparrow}(x') J(x,x')\,dx'}{F_\lambda^{\uparrow}(x')}$$

$$r_\lambda(x) \approx \eta(J) = BF\big|_{F \equiv 1} = \int_{x' \in S} J(x,x')\,dx'$$

where $\eta(J)$ is the max eigenvalue

$$\eta(J) \approx \frac{I_{NIR}(x) - I_{RED}(x)}{F_{NIR}^{\uparrow}(x) - F_{RED}^{\uparrow}(x)}.$$

$$I_s(x,\tau) \approx \frac{I_{NIR}(x) - I_{RED}(x)}{F_{NIR}^{\uparrow}(x) - F_{RED}^{\uparrow}(x)}$$

Summary

The Main Ideas

- use three wavelengths:

  one in RED (670 nm) where vegetation albedo is low

  one in NIR (870 nm) where vegetation albedo is high

  one in MIR (1640 nm) where cloud droplets absorb

- retrieve cloud optical depth and *effective* cloud fraction using the NIR vs. RED plane and then effective radius using NIR vs. MIR plane

The Results (so far)

- looks promising; it largely removes 3D effects;
- it is not the final answer but a *big* improvement against any single-wavelength retrievals;
- it can
  - fill (cloud) gaps in AERONET aerosol optical depth retrievals
  - estimate (effective) cloud fraction and
  - droplet effective radius

  even for broken clouds

Dealing with 3D issues in cloud-vegetation interactions

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NASA/GSFC

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Howard Barker (Canadian Meteo)

Warren Wiscombe (NASA/GSFC)

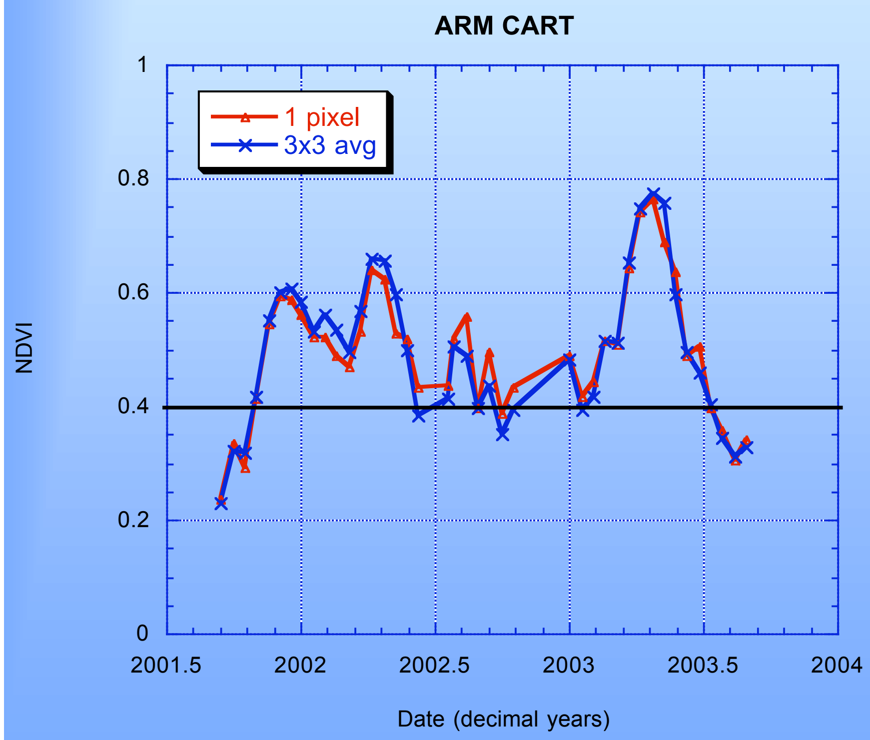
Anthony Davis (LANL)

Brent Holben (NASA/GSFC)

Seasonal applicability

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

ARM CART site, OK



Bondville, IL